Anticipated Effectiveness of Active Noise Control in Propeller Aircraft Interiors as Determined by Sound Quality Tests

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Abstract: Two experiments were conducted, using sound quality engineering practices, to determine the subjective effectiveness of hypothetical active noise control systems in a range of propeller aircraft. The two tests differed by the type of judgments made by the subjects: pair comparisons in the first test and numerical category scaling in the second. Although the results of the two tests were in general agreement that the hypothetical active control measures improved the interior noise environments, the pair comparison method appears to be more sensitive to subtle changes in the characteristics of the sounds which are related to passenger preference.

INTRODUCTION

Active noise control technology offers the potential for weight-efficient aircraft interior noise reduction, particularly for propeller aircraft. However, there is little information on how passengers respond to this type of interior noise control. This paper presents results of two experiments which use sound quality engineering practices to determine the subjective effectiveness of hypothetical active noise control (ANC) systems in a range of propeller aircraft.

FACILITY AND NOISE STIMULI

Binaural recordings, using an acoustic mannequin, were made in five different propeller aircraft during cruise operations. These were used to create modified stimuli with spectra approximating what could be achieved by ANC technology with three levels of sophistication and three levels of effectiveness. The five aircraft were: 1. single engine turboprop, 15 passenger/cargo; 2. twin turboprop, 7-10 passenger business; 3. single 4-cyl. piston, 4 place GA (general aviation); 4. twin turboprop, 30 passenger commuter; 5. single 6-cyl. piston, 6 place GA. Nine modified spectra for each aircraft were obtained by reducing 3, 7, or 15 low frequency tonal components within each signal by three different amounts. Three levels of reduction (7 dB, 14 dB and 21 dB) for the fundamental propeller tone of each aircraft were selected to represent the effectiveness of hypothetical ANC systems. The tests were conducted in an acoustic simulation facility which uses interior trim and seats from Boeing 727/737 aircraft to provide the visual ambiance of a modern aircraft interior. The simulator is approximately 24 feet long and 11.5 feet wide and provides tourist class seating for 45 passengers. Noise stimuli for the subjective judgment tests were presented to the test subjects through electrostatic headphones to preserve the directivity and spatial information afforded by the binaural recording system. Each stimulus had a rise and fall time of 0.3 sec and a total duration of 3.6 sec

EXPERIMENTAL DESIGN

In the the first test, 40 subjects made preference judgments on pairs of sounds consisting of one of the spectrally modified ANC (target) sounds and its original unmodified (reference) sound. Each target stimulus was compared with the reference stimulus presented at loudness levels -6, -2, +2, and +6 dB relative to the loudness level of the target stimulus. In addition, the interior noise of a commercial jet aircraft recorded during cruise was used as a reference stimulus to determine the subjective differences in level between the unmodified stimuli for each aircraft type. A total of 200 pairs of sounds was required to cover all conditions. The pairs were randomly assigned to 4 sessions of 50 pairs. An additional set of 4 sessions were prepared which had the order of pairs in the session and the order of stimuli within each pair reversed to provide balance in presentation order of pairs within sessions and A-B and B-A orders of presentation for the target and reference stimuli. Subjects were tested in groups of five, four groups exposed to the four original sessions and four groups exposed to the reverse order sessions. The order of presentation of the sessions was balanced across the groups. The subjects were asked to *"indicate which member of the pair you preferred"* by circling A or B on a response score sheet.

In the second test, an additional 40 subjects made numerical category scaling noisiness judgments on the same set of ANC and original stimuli presented at the same levels as in the first test, a repeat of the set at those levels and repeats presented at three additional loudness levels. In addition, the same jet aircraft interior noise as in the first test was presented at 10 levels over a range slightly exceeding the loudness levels of all the propeller aircraft interior noises. These 260 stimuli were randomly assigned to four sessions of 65 stimuli each. An additional set of 4 sessions were prepared which had the order of stimuli in the session reversed to provide balance in presentation order. As in the first test, subjects were tested in groups of five, four groups exposed to the four original sessions and four groups exposed to reverse order sessions. The order of presentation of the sessions was also balanced across the groups. The judgments were made on a graphical scale with equal entervals labeled 0 to 10. The subjects were asked to *"indicate how noisy you judge the sounds to be by placing a slash mark along the scale"*. Arrows on the scale indicated the *"Less noisy"* and *"More noisy"* directions of the scales.

RESULTS AND DISCUSSION

In the first test, the differences in equivalent subjective level, ΔESL, between the unmodified sounds and the ANC sounds for each aircraft type were found to be more highly correlated with the differences in loudness measured in terms of Zwicker loudness level (ref. 1) than other common metrics. Figure 1 shows that the differences in subjective and measured loudness for the ANC conditions were greatly dependent on aircraft type. The greatest differences were found for A/C 2 and the least for A/C 1 and 5. Inspection of the spectra indicated the dominance of the propeller tone components relative to broadband components for A/C 2 as compared to the other aircraft.

In the second test, the ΔESLs between the unmodified sounds and the target stimuli for the same ANC conditions of the first test were also found to be more highly correlated with differences in the Zwicker loudness level than other common metrics. Figure 2 shows the greatest differences again were found for A/C 2 and the least for A/C 1 and 5. However, the magnitude of the ΔESLs were somewhat smaller than in the first test. It was also found in this test that the Zwicker loudness levels were more highly correlated than other metrics with the equivalent subjective levels for all the stimuli as a group.

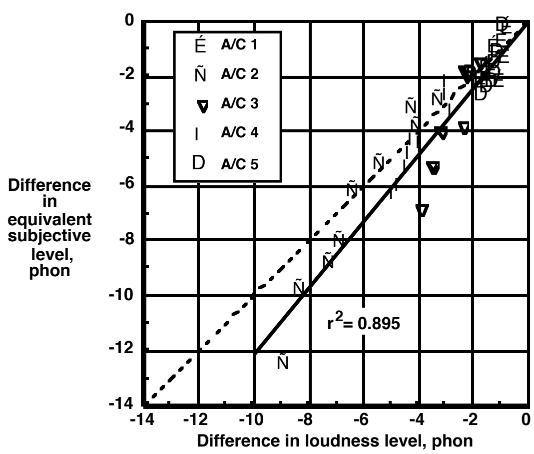

FIGURE 1. Effect of ANC conditions on preference response relative to unmodified sounds.

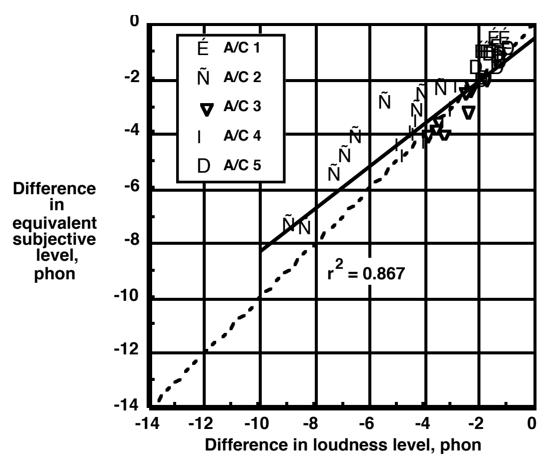

FIGURE 2. Effect of ANC conditions on noisiness response relative to unmodified sounds.

While the noisiness of the different stimuli and change in noisiness effected by an ANC condition are well predicted by loudness level and change in loudness level, other characterisics of the sounds play an important part in determining the subjects' preference in the characteristics of interior noise in propeller aircraft. Multiple regression analyses using loudness and other "sound quality" characteristics on the changes in preference resulted in an increase in r^2 to 0.956 from 0.895 in the first test; tonality (ref. 2) was found to be next in importance to loudness.

REFERENCES

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